

GAS SUPPLY ARRANGEMENT OF A MARINE VESSEL AND METHOD OF CONTROLLING GAS PRESSURE IN A GAS SUPPLY ARRANGEMENT OF A MARINE VESSEL

- 5 Invention relates to a gas supply arrangement of a marine vessel according to preamble of claim 1 and to method of controlling gas pressure in a gas supply arrangement of a marine vessel according to the preamble of claim 11.

10 The propulsion system of LNG (Liquified Natural Gas) tankers is usually powered by making use of the cargo. Storing of the gas in the tanker is arranged by using heat insulated cargo tanks into which an ullage space section and a liquid phase section are formed. The pressure in the cargo tanks is approximately at atmospheric pressure level and the temperature of the liquefied gas is about minus 163 °C. Although the insulation of the cargo tank is extremely good, gradually increasing of the LNG temperature causes formation of so called natural boil-off gas. The

15 natural boil-off gas must be removed in order to avoid extensive increasing of pressure in the cargo tanks. The natural boil-off gas may be utilised in tanker's consumption devices like propulsion system. However, the amount of natural boil-off gas is not sufficient for providing all propulsion energy required in all circumstances and therefore the vessel must be provided with additional means for acquiring extra gas, so called forced boil-off gas. Additionally the usage of the gas as

20 source of propulsion energy sets requirements for the pressure level and stability of the gas.

25 For example in a patent publication FR 2722760 there is shown an arrangement in which liquid gas is supplied to a so called forced boiling vaporiser in which the liquid gas vaporises into gas form, which in turn may be combined with the natural boil-off gas.

30 EP 1348620 A1 shows a gas supply apparatus in which the natural boil-off gas is led to a compressor, which increase the pressure of the gas prior to feeding it to

- consumption via a feed line. The capacity of the compressor feeding the natural boil-off gas is controlled by the pressure at the feed line. Additionally, the apparatus also includes a forced boiling vaporiser in which the liquid gas previously pumped to the higher pressure is vaporised. In this arrangement the forced boiling gas portion is combined to the natural boil-off gas after the pressure of the natural boil-off gas has been increased. This arrangement is mentioned to decrease the work required to compress the gas to a given pressure. It has, however, some problems, which are discussed below.
- 10 The supply amount of the forced boiling gas is controlled by on-off valve positioned prior to the vaporiser, the control being based on the gas cargo tank pressure. The operation of the pump is also controlled by on-off control based on the pressure of the gas cargo tank. The line between the gas cargo tank and the vaporiser has also a branch for returning a part of pumped liquid gas back to the gas cargo tank.
- 15 The amount of returned part is controlled based on the pressure of the gas line before the vaporiser. A problem in this arrangement is the returning of the pumped liquid gas back to the cargo tank. That is not desired due to the heating effect of the liquid gas slightly warmed up by the pumping and circulation.
- 20 As the consumption of the gas at the outlet side (the feed line) of the vaporiser and compressor varies, the process must be controlled so that the pressure in the gas cargo tank and/or in the feed line will not rise too much and so that required amount of gas may be supplied. When the formation of the natural boil-off gas is not strong enough or consumption is suddenly increasing, the pressure in the ullage space of the gas cargo tank decreases and the operation of forced boiling vaporiser and liquid gas pump is started. After operating the pump and the vaporiser a while the pressure will increase to adequate level. Then the pump may be shut down and the valve of the forced boiling vaporiser is also closed. Particularly because the operation of the vaporiser is on-off controlled, the variation of the pressure in the feed line is inevitably very strong. This is even more emphasised by the fact that the vaporiser is typically dimensioned for 100% consumption, which
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makes the control very rough. Therefore, this kind of a control system is very complicated and also somewhat unstable. Similar arrangement to this is shown in EP 1291576 A2.

- 5 An objective of the invention is to provide a gas supply arrangement for a marine vessel, which solves the above mentioned and other problems of the prior art. It is also an objective of the invention to provide a method of controlling gas pressure in a gas supply arrangement for a marine vessel with liquefied gas cargo tank, which provides even pressure at the feed line and reliable gas supply for consumption
10 devices of the vessel.

Objectives of the invention are met substantially as is disclosed in claims 1 and 11, and in more detailed manner in other claims. In the following the invention will be described with a reference mainly to one cargo tank. However, it is clear that a ma-
15 rine vessel may be provided with several cargo tanks each having an individual gas supply arrangement or several cargo tanks may be connected parallel having a shared gas supply arrangement.

According the invention, the gas supply arrangement of a marine vessel being
20 adapted to carry liquefied gas in its cargo tank having an ullage space section and a liquid phase section and to utilise the cargo as fuel to provide power for the vessel, comprises

- a first gas supply line, which connects an ullage space section of the cargo tank and a gas main supply line and which is provided with a compressor for raising the
25 pressure of the gas to an adequate level, and
- a second gas supply line, which connects liquid phase section of the cargo tank and the gas main supply line and which is provided with at least a pump for raising the pressure of the liquid gas and for pumping it forward.

It is mainly characteristic to the invention that the second gas supply line is addi-
30 tionally provided with a gas reservoir having an ullage space section and liquid phase section, which reservoir is connected to the liquid phase section of the cargo

tank by a first duct section of the second gas supply line and to the gas main supply line by a second duct section of the second gas supply line.

5 Preferably the reservoir is provided with temperature control unit by means of which the pressure in the reservoir may be indirectly controlled. This kind of an arrangement provides a gas supply system, with which the pressure of the gas in the main supply line may be easily controlled and maintained very stable.

10 The temperature control unit of the reservoir comprises adjustable heating device for heating the liquid phase gas in the reservoir. By heating the liquid it is possible to activate gas evaporation of the liquid gas the liquid phase section. The heating device is provided with control device being responsive to the gas pressure in the reservoir. This provides accurate and reliable means for controlling pressure. The reservoir is preferably also provided with surface level control arrangement for
15 controlling the surface level of the liquid phase section. Preferably the heating device is provided with a heat exchanger external to the reservoir being in connection with the liquid phase section of the reservoir by piping. The second duct section of the second gas supply line is preferably provided with an automatically controlled closing valve, which may close the supply of gas quickly in case the gas consumption
20 stops rapidly.

The reservoir is advantageously dimensioned to have a volume corresponding to few hours gas consumption through the gas main supply line, which provides a possibility of using the reservoir as buffer gas source. The dimensioning depends
25 on the specific application in question e.g. discharge time of the tanks may be taken into account.

The reservoir is so connected that the first duct section of the second gas supply line extends into a liquid phase section of the reservoir, and the second duct section
30 of the second gas supply line extends from the ullage space section of the reservoir to the gas main supply line.

In the method according to the invention of controlling gas pressure in a gas supply arrangement of a marine vessel with liquefied gas cargo tank having an ullage space section and liquid phase section, and with a gas consumption device, gas
5 from the cargo tank is led to the consumption device via a first gas supply line, which is provided with a compressor, the compressor raising the pressure of natural boil-off gas to an adequate level, and additionally or alternatively via a second gas supply line, which connects liquid phase section of the cargo tank and the gas consumption device, the second gas supply line is provided with a pump for raising
10 the pressure of the liquid gas and pumping it forward. In the second gas supply line gas is fed into a reservoir having an ullage space section and liquid phase section, in which the gas is temporarily stored. From the reservoir gas is further introduced to the gas consumption device. Gas is evaporated in the reservoir and the pressure of the gas in the in the second gas supply line is controlled by controlling the
15 temperature of the liquid phase section of the reservoir.

The invention has several advantages. First of all, the pressure control is very accurate due to the novel way of controlling the pressure by heating the liquid gas. Additionally the invention provides a buffer for gas fuel for the consumption devices
20 in case the connection to the cargo tank must be cut off.

In the following the invention will be described with the reference to the accompanying schematic drawing, in which figure 1 shows a preferred embodiment of the gas supply arrangement according to the invention.
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Figure 1 shows schematically cross section of a marine vessel 6, like LNG tanker. The vessel 6 is adapted to carry liquefied gas in it cargo tanks. Normally there are several tanks in a tanker, but in the figure 1 only one cargo tank 4 is shown for clarity reasons. The cargo tank 4 is filled so that there is always an ullage space section 4.1 filled with gas in gaseous form and a liquid phase section 4.2 filled with
30 liquefied gas. During the storing of the liquefied gas in the cargo tank 4 the gas is

evaporating changing its phase and transferring to the ullage space 4.1. The evaporated gas, so called natural boil-off gas, may be utilised in a consumption device 5 of the vessel 6. The consumption device 5 is preferably a gas engine providing propulsion power. In the figure only one consumption device 5 is shown but it is clear that there may be several devices.

The vessel 6 is provided with a gas supply arrangement 1, which comprises a first gas supply line 2. The first gas supply line 2 extends from an ullage space section 4.1 of the cargo tank 4 to a gas main supply line 7 leading to the consumption device 5. The first gas supply line 2 is adapted for delivering the evaporated boil-off gas from the cargo tank 4 to the consumption device 5 of the vessel 6 via a main supply line 7. The pressure in cargo tank 4 is maintained slightly over-pressurised. The first gas supply line 2 is provided with a compressor 2.1 for raising the pressure of the boil-off gas to an adequate level for usage in the consumption device 5. The pressure level in the gas main supply line 7 must be maintained at appropriate pressure but below maximum design limits. The lower limit is typically ruled by requirements of the gas engines of the vessel being as the consumption device 5. The capacity of the compressor 2.1 is controlled by making use of pressure measurement device 10 provided in the cargo tank ullage space, so that the pressure in the cargo tank remains within certain design limits.

The gas supply arrangement 1 comprises also a second gas supply line 3. The second supply line 3 is arranged for converting the liquefied gas into gaseous form for example in case the amount of the natural boil-off gas is not big enough. The second supply line 3 is principally parallel line to the first supply line 2, leading from the cargo tank 4 to the main supply line 7. Therefore it is provided with a liquid gas pump 3.1 for raising the pressure of the liquid gas to approximately level of the main supply line 7. The pump 3.1 is preferably positioned in the liquid phase section 4.2 of the cargo tank 4 so that it pumps the gas in liquid form. The converting the liquefied gas into gaseous form is accomplished by providing the second supply line 3 with a gas reservoir 3.2, into which the pump 3.1 transfers the liquid gas

via a first duct section 3.4 of the second gas supply line 3. The first duct section 3.4 is preferably provided with a check valve or automatic controlled close valve 3.12 for preventing the return of the liquid gas back to the cargo tank 4. The pump 3.1 and valve 3.12 are operated under control of a surface level control arrangement 8 provided in the reservoir 3.2. The pump is started when the level of the surface is at its lower limit 8.1 and the pump is running until the surface is raised to its upper limit 8.2. Preferably the surface limits are selected so that the reservoir is 20% filled at minimum and 80% filled at maximum. The output of the pump 3.1 is preferably selected so that the ascending speed of the surface is relatively low during the filling. This way the filling of the reservoir 3.2 has minimum impact on the gas pressure in the ullage space section 3.3 of the reservoir 3.2. The effect of the ascending surface to the pressure may be at least partly compensated by properly controlling a reservoir temperature control unit, which will be described later. Due to the properties of the gas i.e. the volume of the gas in gaseous form being approximately 600 times as much as is in liquid form, the output of the pump 3.1 may be selected in this manner without a risking the gas formation capacity. Typically the cargo tank 4 is provided with a so called spray pump, and the pump 3.1 may be a separate pump or the spray pump.

Formation of gaseous gas in the reservoir 3.2 is accomplished partly by arranging the ullage space section 3.3 in the reservoir i.e. taking care that the upper limit 8.2 of the surface of the liquid gas is not too high. However, mainly the gas evaporation and simultaneously the pressure level in the ullage space section 3.3 is controlled by controlling the temperature of the liquid phase section 3.7 in the reservoir 3.2. This is accomplished by the temperature control unit 3.6. The unit comprises pressure sensor 9 provided in the reservoir, based on measurement value of which the temperature of the liquid phase section 3.7 is controlled. The principle of the control is based on the fact that the higher the temperature, the stronger the evaporation of the gas is. So, when the liquid phase section 3.7 is heated the formation of gaseous gas is increased and the simultaneously the pressure depending on the consumption, of course. This applies also vice versa.

- The heating of the liquid gas in the liquid phase section 3.7 is accomplished by a heating device. The heating device according to a preferred embodiment of the invention comprises an external heat exchanger 3.9 into and from which the liquefied gas is flowing through piping 3.10. The liquefied gas is heated by a heat transfer medium flowing in the other side 3.8 of the heat exchanger 3.9. There may be a circulation pump 3.11 for facilitating the flowing of the liquefied gas, but the piping may be so dimensioned that free circulation (based on density difference) will occur. Heat transfer rate and thus heating of the liquefied gas is controlled by a valve 9.1, which controls the flow of the heat transfer medium. The heat transfer medium may be e.g. water or steam, but practically any suitable heat source, also electric heater, may be utilised. In the figure 1 also a possible direct heater 3.9' is shown with dotted line.
- Gas from the reservoir is led to the gas main supply line 7 via a second duct section 3.5 of the second gas supply line 3. When the output of the boil-off gas (first gas supply line 2) is not enough for consumption demand, the pressure in the main supply line 7 will modestly decrease and the gas will flow through the second duct section 3.5 from the ullage space 3.3 of the reservoir 3.2. This causes a minor pressure drop in the ullage space 3.3, which is detected by the sensor 9. The measurement is transmitted to a control device (not shown for clarity reasons) which sends a command to the valve 9.1 in order to actuate opening movement. This, in turn, increases the heat transfer from the heat transfer medium to the liquefied gas raising its temperature. And, since temperature of the liquefied gas is raised, the evaporation of the gas is increased and the pressure drop in the ullage space section 3.3 will be compensated. In case other type of heating device would be used its output power would be controlled by the pressure measurement sensor 9.
- This kind of a pressure control arrangement is very stable and easy to adjust to maintain the supply line pressure within the required limits. Additionally the reser-

voir 3.2 provides a buffer for example for situation when the cargo tanks 4 must be cut off from the vessel's gas supply. For example while discharging the cargo tank 4 at port terminal, it may be advantageous to have some buffer volume and therefore the reservoir 3.2 may be dimensioned to have a volume corresponding to at least four hours gas consumption through the gas main supply line 7.

The second duct section 3.5 of the second gas supply line 3 is provided with an automatically controlled closing valve 3.13. In case the gas consumption stops rapidly, the valve 3.13 is closed. In this case the pressure in the reservoir 3.2 will be allowed to increase to slightly higher level than normally. The reservoir 3.2 is provided with a pipe 3.14 which opens into the liquid phase section of the reservoir and which leads back to the cargo tank 4. The pipe is provided with a valve 3.15 for controlling the flow of liquid gas. This provides eg. A possibility of returning heavier hydrocarbon compounds back to the cargo tank 4.

During the filling of the reservoir 3.2 the pressure in the ullage space 3.3 partly increases due to the ascending surface level, this is registered by the pressure sensor 9, which information is transmitted also to the temperature control unit 3.6.

Control dependencies in the figure 1 is shown informally by dotted lines for clarity reasons. However, it is clear that the control system may be realised by various manners, using centralised or distributed control arrangements.

The invention is not limited to the embodiment shown but several modifications of the invention are conceivable within the scope of the appending claims.